Melting at the Liquidus: Rapid Melting Experiments with a Titanium-Niobium Alloy

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Constant-power pulsed melting experiments were conducted on Nb-47mass%Ti specimens. The specimen temperature through melting was obtained from simultaneous measurement of the radiance temperature and normal spectral emissivity until specimen collapse (> 70% melted). The effect on the melting behavior of varying the grain size and the imposed heating rate was studied. Interrupted experiments indicated that the specimen surface and grain boundaries serve as nucleation sites, with the melt fronts moving from grain boundaries to grain centers. Experiments were conducted using specimens with grain diameter between 40 and 167 μm and heating rate from 10^2 to 10^4 K/s.

The melting behavior observed in the experiments differed substantially from that predicted using the equilibrium phase diagram to determine the molten volume fraction as a function of temperature. In order to understand the behavior, a model of diffusion-limited melting was developed. The model incorporates the spherical grain geometry and imposes solute conservation and local equilibrium at the moving solid/liquid interface. Compositions within the liquid and solid regions satisfy time-dependent diffusion equations as well as boundary conditions at the interface. Thermal diffusion times, much shorter than the time scales of interest, were ignored. In addition to the specimen composition, grain diameter and imposed heating rate, the model uses literature values for the ratio of latent heat to specific heat, the equilibrium liquidus and solidus curves, and the liquid and solid diffusion coefficients.

There is good agreement between the melting behavior predicted by the model (with zero free parameters) and the experimental data. In particular, as predicted by the model, identical melting behavior was observed when the product of heating rate and grain diameter squared was constant. In addition, at sufficiently high heating rates, the majority of the material melted at the liquidus temperature of the bulk alloy, also predicted by the model. This behavior contrasts with the smooth increase of the molten fraction from the solidus temperature to the liquidus temperature predicted for equilibrium melting. No indication of loss of local equilibrium at the solid-liquid interface is implied by the experimental results.